Long Range Forecasting of Tropical Cyclone Formations in the Western North Pacific

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Motivation

DoD operational planning and METOC support are out of sync:

1. **Focus of most forecasting: tau ✹ 72 hours**
2. **Short range forecasts often come too late to have much influence on planning.**
    a. **Naval exercises**
    b. **Battlegroup transits**
    c. **Logistical support**
3. **For TCs, long lead support based on climatology: challenging if it is to be helpful for the planner**
4. **There is potential value if skillful long range forecasts of TCs (tau 2 weeks) can be made for operational planning:**
    a. **Location**
    b. **Timing**
    c. **Assets**
    d. **Tactics**
5. **Our goals:**
    a. **Develop skillful long range forecast (LRF) systems for TC activity starting with TC formations**
    b. **Help improve long lead support for operations affected by TCs**
    c. **Assess the operational value of such LRF systems**

Model Development and LRF Process

Build statistical model based on relationships between TC formations and LSEFs

Statistical model of TC formation probability

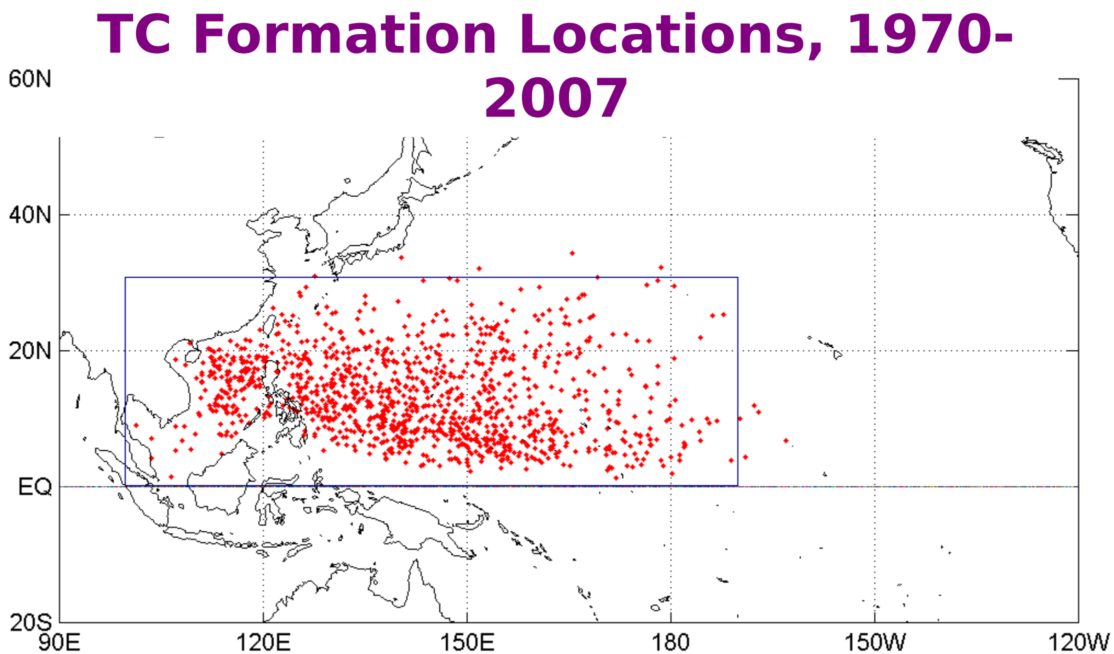
Statistical-dynamical model output: long range forecast TC formation probabilities

Use dynamical, ensemble-based, long range forecasts of LSEFs to force statistical model

Inputs, outputs, are all on a daily, 2.5° scale

Study Region & Period

xtensive data necessary for model development



1. **Red dots: formation points for all 1,122 TCs that formed during 1970 -2007, from JTWC best track data.**
2. **Study region: Western North Pacific (WNP), 100°E–190°E and 0°N–30°N.**
3. **Study period: 1982-2007.**

Key Assumptions

1. **There are large scale environmental factors (LSEFs) that influence the formation of tropical cyclones (TCs).**

2. **These LSEFs are statistically related to the likelihood of TC formation.**

3. **The effects of the LSEFs need to be modeled at resolutions that reflect the scales at which they affect TCs (hundreds of miles, several days).**

4. **If the LSEFs are predictable, then TC formation probabilities should be predictable as well.**

Large Scale Environmental Factors (LSEFs)

Gray (1968, 1975, 1979) identified environmental genesis parameters, or LSEFs, that affect tropical cyclogenesis.

Other authors have varied the list of LSEFs, but agree on the basic physical processes:

Thermodynamic

- **Warm sea surface temperature (SST)**
- **High mid-tropospheric humidity**

Dynamic

- **Weak vertical wind shear**
- **Mean upward vertical motion**
- **Positive low-level relative vorticity**
- **Sufficient separation from the Equator**

Describe an environment favorable for TC formation

Data Used in Statistical Model Development

JTWC Best Track

Archive of TC data for the WNP. Contains, at a minimum, the latitude and longitude of the TC center every six hours. Includes tropical depressions through super typhoons. We define the formation day as the date of the first record within the best track file.

(Cu *et al.* 2002)

NCEP Reanalyses

Source of analyzed atmospheric LSEF data used in this study: NCEP/NCAR Reanalysis Projects (R1) and NCEP/DOE AMIP-II Reanalysis (R2). Daily mean fields at 2.5° horizontal resolution.

(Kalnay *et al.* 1996; Kistler *et al.* 2001; Kanamitsu *et al.* 2002)

NOAA OISST

Source for SST data. Combines in-situ and satellite-derived SST measurements, interpolated and adjusted for biases as necessary. Weekly means at 1° horizontal resolution.

(Reynolds *et al.* 2002)

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Regression Model

ogistic regression relates probability of TC formation to LSEF va

he form of this relationship is:

$$p_F = \frac{e^{(b_0 + b_1 x_1 + \ldots + b_6 x_6)}}{1 + e^{(b_0 + b_1 x_1 + \ldots + b_6 x_6)}}$$

e LSEFs:

ar (u and v, 200 hPa minus 850 hPa)
(850 hPa)
hPa)

(850 hPa)

ificance of each proposed independent

nagnitude and sign of each LSEF’s
ficient in order to relate formation probability

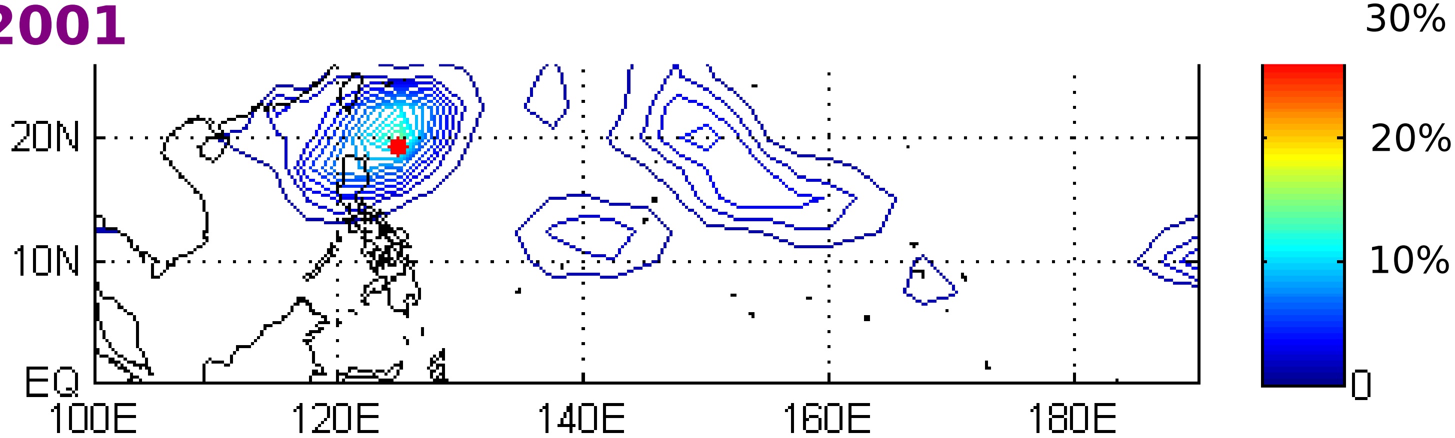
Regression Model

The statistical model tells us that:

1. TC formation probabilities are significantly related to the LSEFs as follows:
    a. Positively impacted by SST, vorticity, distance from the equator, and upward vertical motion
    b. Negatively impacted by shear magnitude
2. Relationships are physically plausible
3. Selection of LSEFs for model based in part on availability of LRFs of LSEFs

Regression Model: Output and Verification

Model Hindcast: TC Formation Probabilities for 18-24 Sep 2001



colors show probability a TC will form in a given grid box during the 7-day period.

Red dot indicates formation site for TC that formed on 21 Sep 2001.

1. **Verify model by use of zero lead hindcast independent data**

2. **Compare elevated formation probabilities with actual TC activity**

2. **Example shown above is from 25 years of zero-lead hindcast data in which statistical model was forced with reanalysis LSEF values.**

3. **Hindcasting used to assess potential skill of regression model.**

Model Verification

Several scoring tools were used to assess the performance of the model

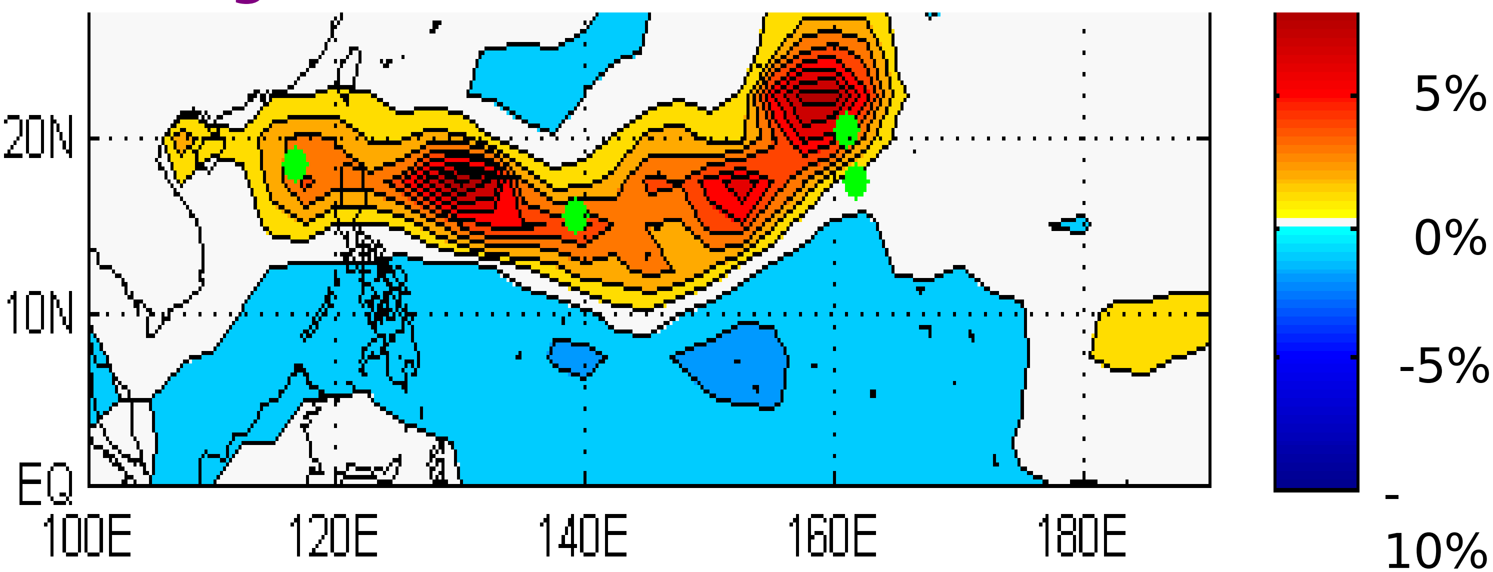
Based on 25 years of zero lead hindcasts, 1982-2006:

1. **Accuracy**: 681 hits (TCs formed in an area of elevated formation probability)
   - 81 misses
2. **Brier Skill Score:** Positive, indicating skillful improvement over climatology
3. **Relative Operating Characteristic:** ROC score = 0.7 (perfect = 1.0). Indicates good ability to discriminate between formations and non-formations.
4. **Reliability Analyses:** Indicate high reliability, but slight under-prediction.

- **Model has high skill in zero lead hindcast mode.**
- **Model has high potential to produce skillful forecasts.**

Model Verification

TC Formation Probability Anomalies (21-27Aug 01)



Hindcast Probs > Climatology

Hindcast Probs < Climatology

1. **Figure shows TC formation probabilities compared to long term mean probabilities.**
2. **Reiterates model has skill over climatology**

Application: Such results can be used identify spatial and temporal regions of elevated or lowered risk for operational planners

Play VIDEO: *2003M03_J2NSLP40rf2B_7DayClimoDiff.avi*

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↑

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LRFs of TC Formation

LSEF LRFs from NCEP Climate Forecast System (CFS)

1. **Fully-coupled, ensemble-based, ocean-land-atmosphere dynamical prediction system**

2. **Operational at the Climate Prediction Center (CPC) since August 2004**

3. **Variables forecasted drive selection of model inputs (no omega)**

4. **Four ensemble member runs per day with integrations out to nine months**

5. **The atmospheric component:**
   a) **Reduced-resolution version of the 2003 operational GFS**
   b) **Reduced to T62L64 (~200km Gaussian grid)**

6. **CFS output data set includes bias correction and hindcast fields**

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LRF System Verification

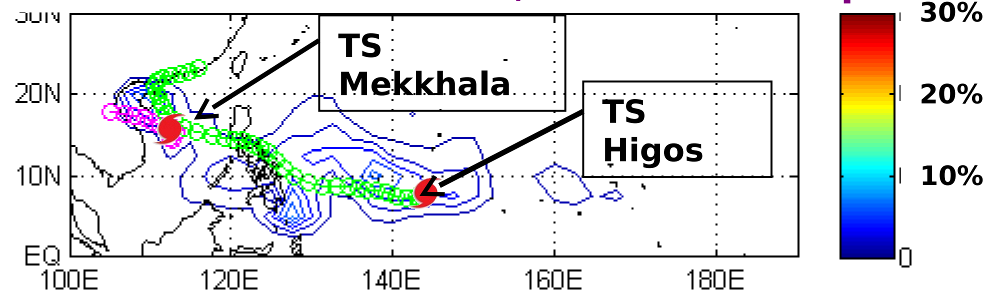
1. Hampered by smallness of the data set
2. Forecast data collection began in September of 2008
3. Some case studies made using forecast data and fall 2008 WNP TCs
4. Case studies show promise for viability of LRF system
5. Significant shortfall is forcing a model built on R2 data with CFS inputs
6. Some indications of CFS shortfalls (timing)
7. Higher resolution CFS under development, and should only improve LRF system performance

2-Week Lead Hindcast Example

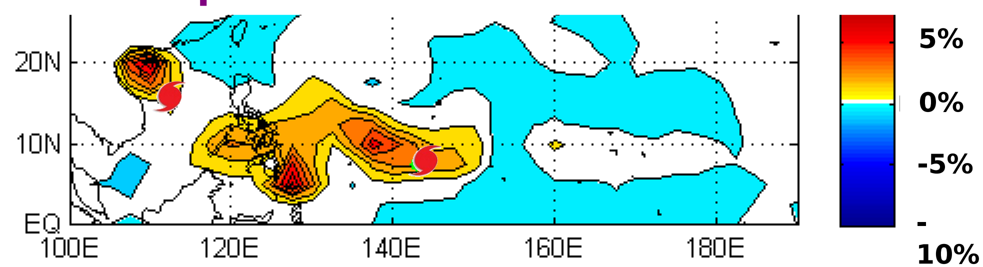
1. **Generated using operational CFS fields employing a four-member ensemble, two week lead**
2. **Note elevated probabilities and positive probability anomalies in and near formation sites**
3. **Observe regions of high TC formation probability correspond with areas of deep convection**

- **Initial hindcasts / forecasts at lead times of 2-8 weeks show promising skill.**

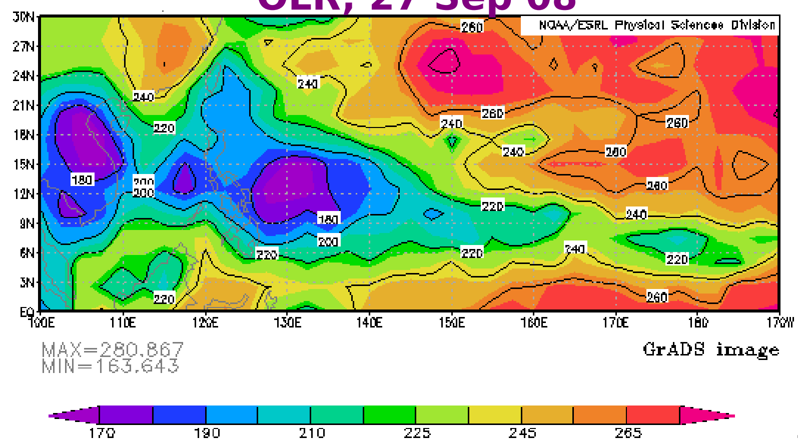
Two-week lead hindcast, valid 24-30 Sep 08



Two-week lead anomaly hindcast, valid 24-30 Sep 08



OLR, 27 Sep 08

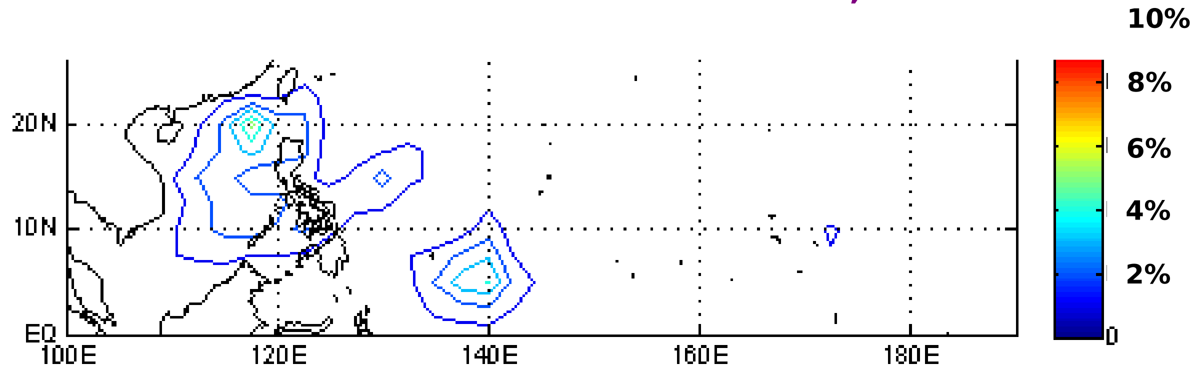


OLR image provided by PSD, ESRL, NOAA, from their website at http://www.esrl.noaa.gov/psd/.

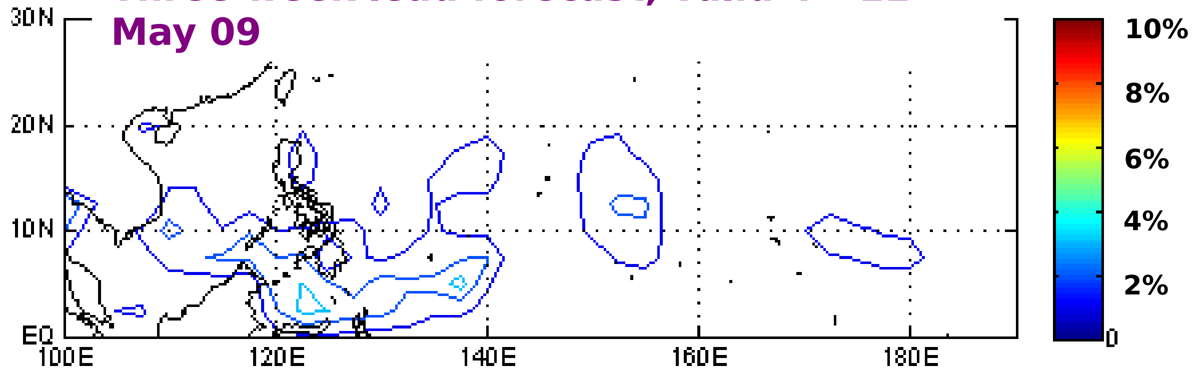
4-, 3-, and 2-Week Lead Forecast Examples

1. **Generated using operational CFS fields employing a four-member ensemble at 4, 3, and 2 week lead times**
2. **Output consistency seems to indicate likelihood of formation.**
3. **Relatively little consistency for these three lead times, but this is not always the case.**

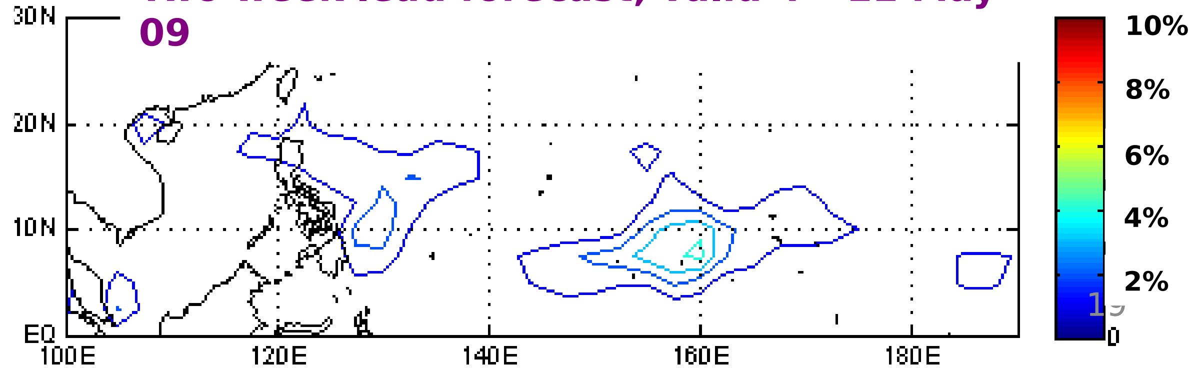
Four week lead forecast, valid 4 – 11 May 09



Three week lead forecast, valid 4 – 11 May 09



Two week lead forecast, valid 4 – 11 May 09



Summary & Way Ahead

1. Developed and verified model relating predictable LSEF parameters and probability of TC formation.
2. Extensive zero lead hindcast tests show model is accurate, skillful, discriminative, and reliable.
3. Initial non-zero lead hindcast and forecast case studies indicate statistical-dynamical LRFs often have skill over climatology at leads out to 8 weeks. In less predictable situations, LRFs tend toward climatology.
4. Predictive potential appears to exceed current long range support capabilities, providing probability of formation at higher spatial and temporal resolution, and at long leads.
5. Will produce and verify experimental LRFs for 2009 TC season. Will use smart climatologies and probabilistic LRF system on experimental basis ISO west Pac Naval exercises in August-November 2009; lead partner: FNMOC.
6. Currently validating the same LRF process for North Atlantic use.

Contact Information

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NPS Smart Climatology: http://met.nps.edu/smart-climo/reports.php
NPS METOC Metrics: http://met.nps.edu/metrics/metrics_reports.html

Model Verification

No standard in literature exists for the verification of spatial forecasts for such rare events. So we chose to use several methods in concert.

Notes on our approach to quantitative verification:

- "Hit" for grid points at or within a 2.5° radius around the JTWC formation point
- Verification on peak formation season to minimize data dilution

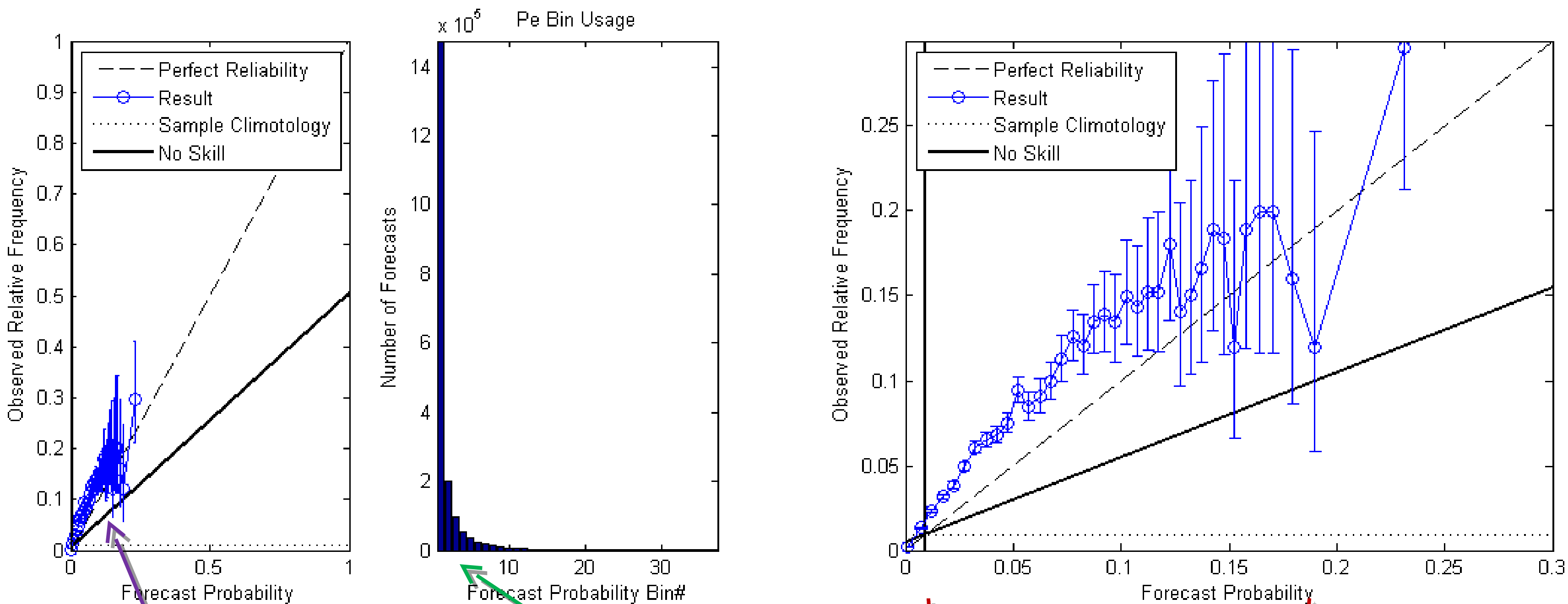
Caveat lector:
Our statistical model generates probabilities based on the favorability of the large-scale environment, thus represents ***the propensity for TC formation, not actual formation****. In order to verify, however, we compare this propensity to actual formations.*

Brier skill score of 0.029 (0.028…0.030), thus a skillful improvement over sample climatology.

95% Confidence Interval

Model Verification

Reliability Diagrams and Bin Histogram



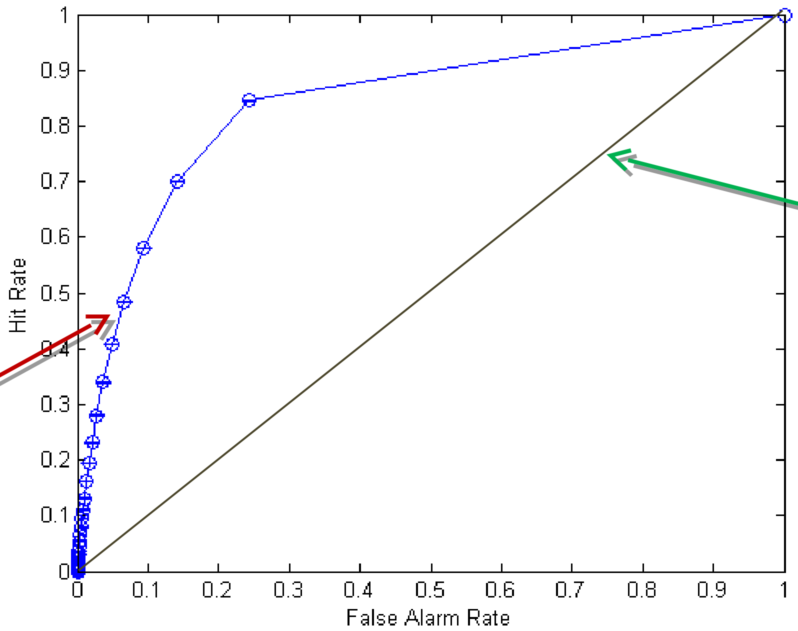
Reasonably reliable and skillful hindcasts.

Model overwhelmingly predicts very small probabilities, which aligns well with the rarity of TCs

Skillful, but slightly underpredictive.

Model Verification

Relative Operating Characteristic (ROC) Curve



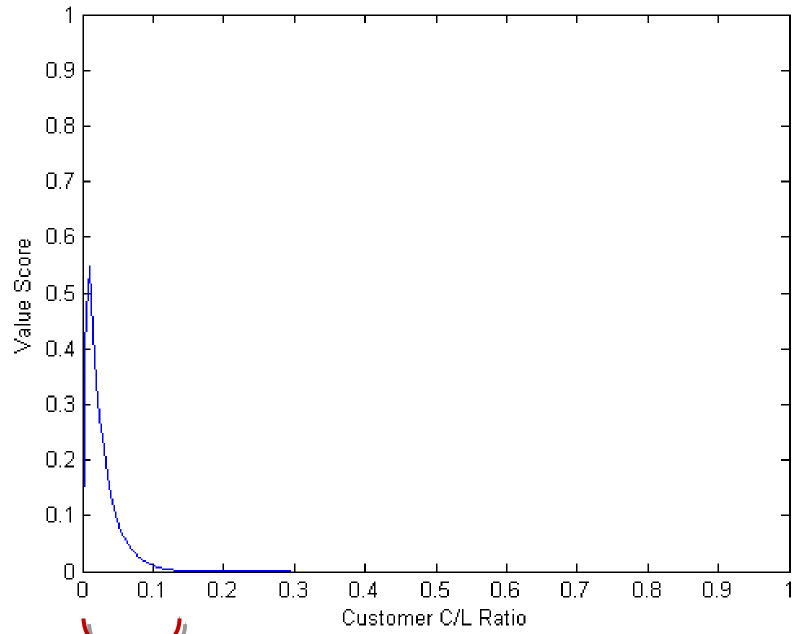
Diagonal represents zero resolution (no discrimination).

Fair discrimination and potential utility to the user.

ROC skill score of 0.68; recall, “1” is a perfect forecast and “<0” is worse than the sample climatology.

Model Verification

Economic Value Diagram (EVD)



Significant potential value for risk adverse customers.

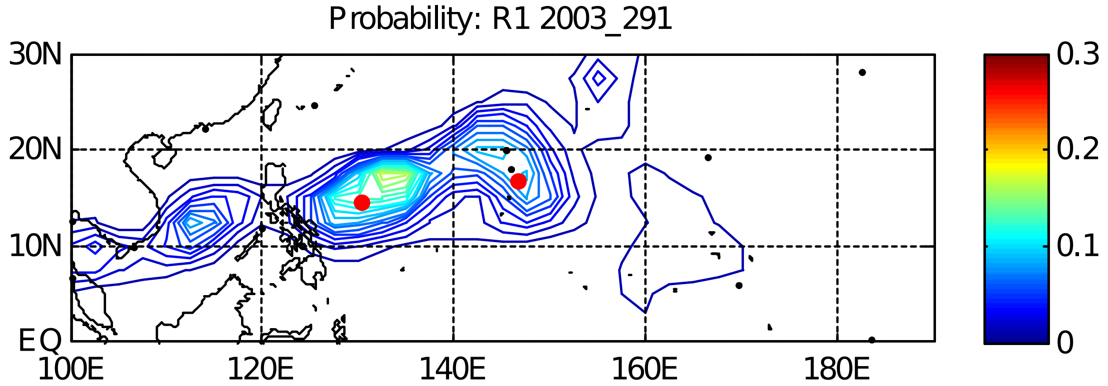
Recall the EVD depicts the potential value-added by following the forecast guidance for each customer (as defined by his cost/loss ratio).

9- and 39-Day Lead Hindcast Examples

Nine-day and 39-day lead hindcast, valid 15-21 Oct 2003.

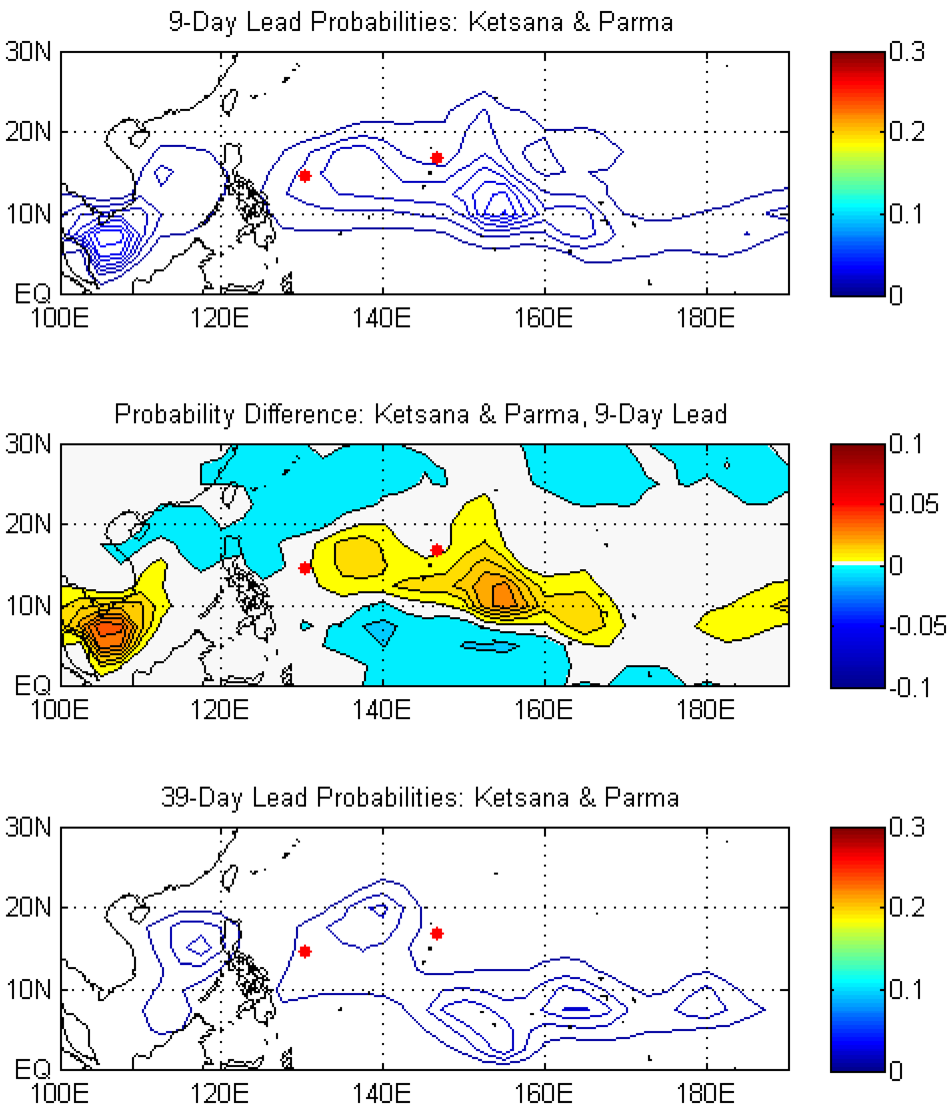
Typhoon Ketsana (20W) and Typhoon Parma (21W)

Using the CFS ensemble mean fields from the hindcast archive at 9-day and 39-day leads.



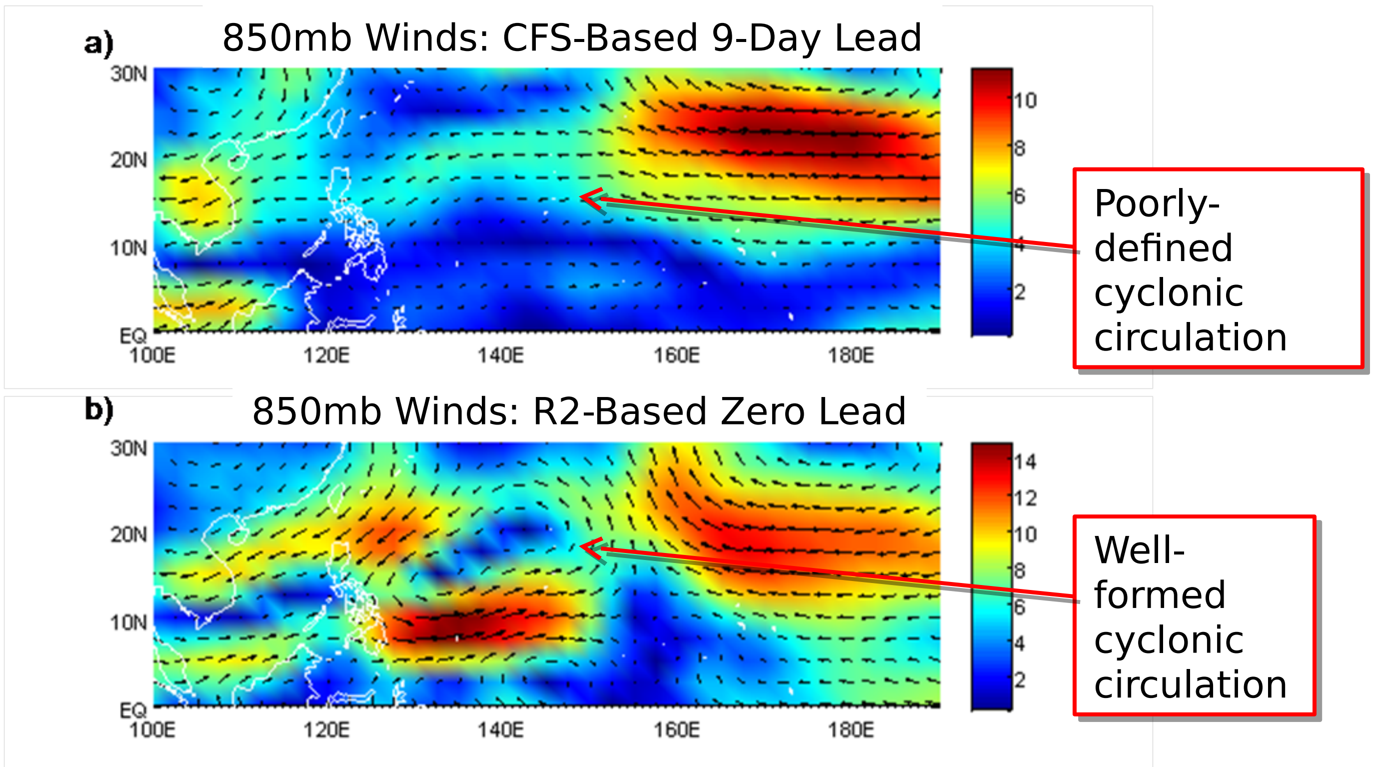
Contoured, seven-day summed probabilities, centered about the 291th day (18 Oct) of 2003, constructed at zero-lead from R1 and OISST fields. The red dots indicate the formation point for Ketsana (left) and Parma (right).

9- and 39-Day Lead Hindcast Examples



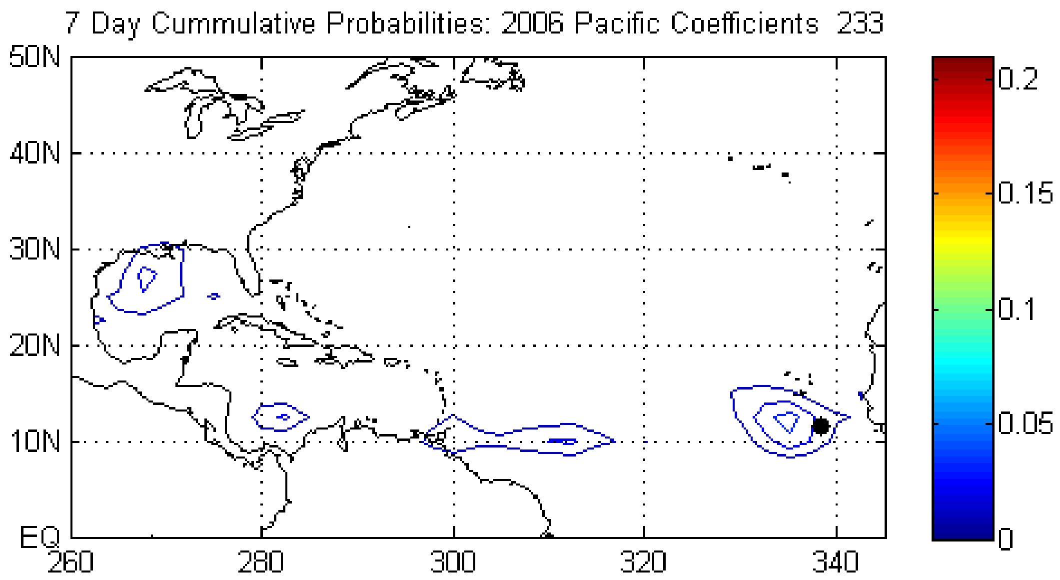
9- and 39-Day Lead Hindcast Examples

The placement and magnitude of the probabilistic output are highly dependant on the component wind fields.



Bias-corrected CFS fields appear to tend towards climatology when the predictability in the climate system is low.

Model Verification



Using North Atlantic LSEF zero-lead hindcast data on WNP based model, we find model has:

- Accuracy
- Skill
- Discrimination
- Reliability

Model Development and LRF Process

1. **Use hindcast LSEF data to build statistical model**

25 years of TC data from JTWC best track dataset

25 years of LSEF data from NCEP reanalysis dataset

1. Multivariate logistic regression used to construct statistical model

Statistical model relating LSEFs to TC formations

4. Model calculates formation probabilities based on predicted LSEFs

3. Predicted LSEFs used to force statistical model

Ensemble based, probabilistic, long range predictions of likely TC formation regions

Data on present state of climate system

Ensemble based, long range predictions of LSEFs from CFS

2. Additional LSEFs derived from available fields

Key

Analysis Element

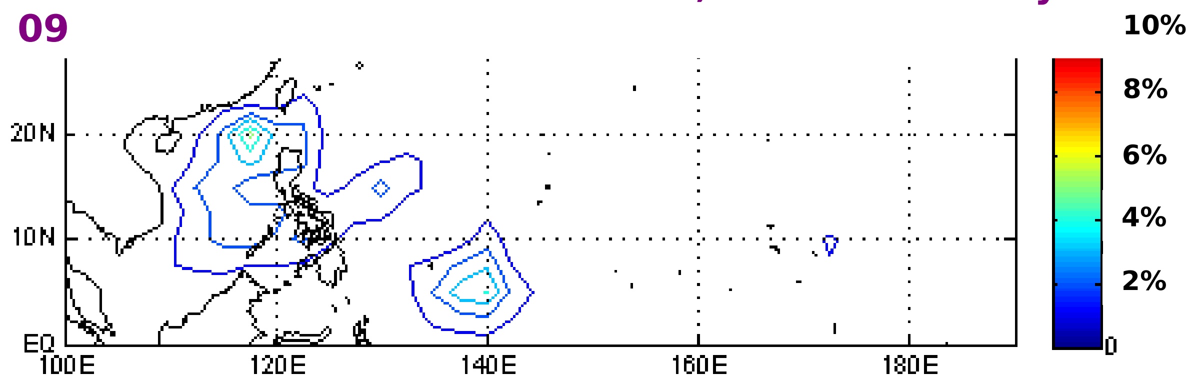
Prediction Element

Inputs, outputs, all done on a daily, 2.5° scale

TCC, 28Apr09, dwmeyer@nps.edu

4-Week Lead Forecast Example

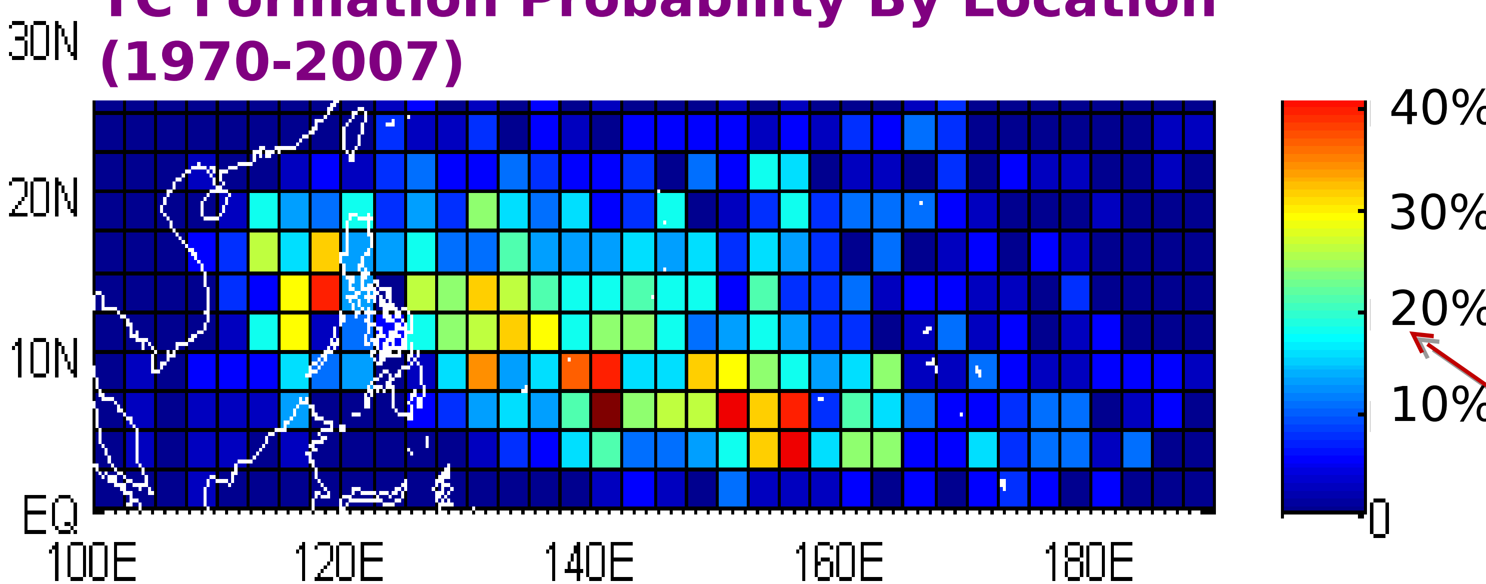
Four week lead forecast, valid 4 – 11 May 09



Generated using operational CFS fields employing a four-member ensemble at 4 week lead

Spatial and Temporal Variability of TCs

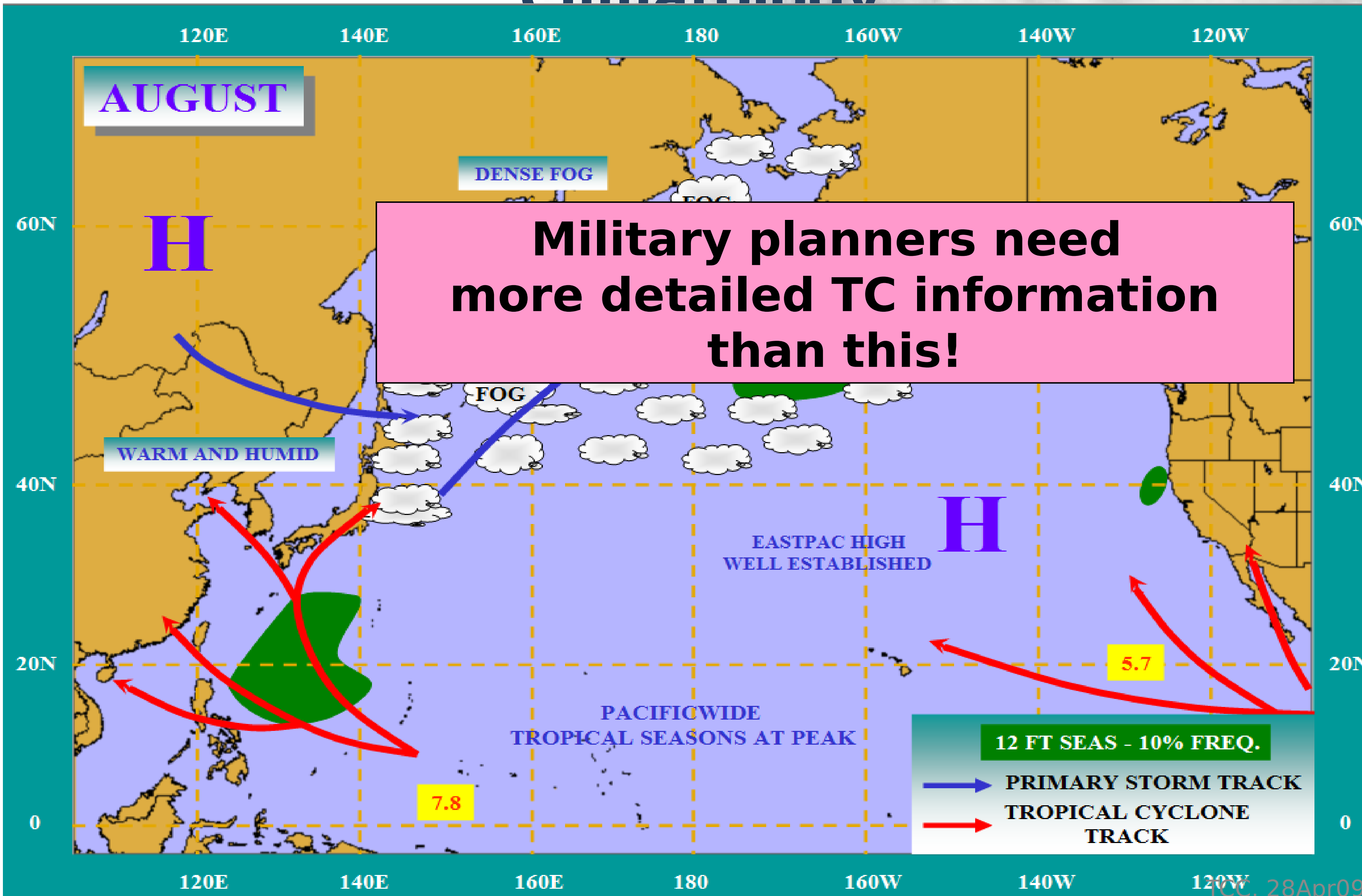
TC Formation Probability By Location (1970-2007)



Probability that a TC will form in a given grid box during a one year period.

1. **Probabilities show distinct spatial variability within WNP.**
2. **Highest formation probabilities occur near climatological position of monsoon trough.**
3. **Pixilation shows 2.5°x2.5° horizontal resolution used in model building.**

Example of Existing Climatological Support from JTWC "Pacific Climatology"



Military planners need more detailed TC information than this!